Multiple Deep Jupiter Atmospheric Entry Probes Delivered By A Modified INSIDE Jupiter Spacecraft

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ABSTRACT

The INSIDE Jupiter (IJ) spacecraft offers a low-cost implementation option for a multiple deep Jupiter probes mission. Trajectory designs already exist that allow a single carrier-relay spacecraft (CRSC) to deliver and support multiple atmospheric entry probes to different latitudes at Jupiter. Such trajectories, based on a CRSC polar flyby, do not require orbital insertion at Jupiter. This greatly reduces radiation exposure and propulsive requirements compared to an orbital mission, and simplifies operations. Recent design studies show that a derivative of the solar-powered INSIDE Jupiter spacecraft, modified for such a flyby trajectory and carrying probes, could serve as the CRSC, decreasing the CRSC's development costs. The simpler IJ-CRSC requirements allow large mass reductions in many of the IJ spacecraft's subsystems, notably removing the large primary propulsion system used for orbit insertion in the original IJ mission. For an IJ-CRSC mission, three probes and their deployment system take the place of that propulsion system. JPL's Advanced Projects Design Team produced the conceptual design for the fully instrumented entry probes (not "microprobes") that can reach ~100-bar levels. Although probe mass estimates vary from 75 to 110 kg depending on technologies assumed, the total mass of the IJ-CRSC spacecraft and probes would be at least 200 kg less than that of an orbital-mission IJ spacecraft. The full poster details the probes' science missions and data return, and non-proprietary engineering aspects.

INTRODUCTION

In 1996 and 1997 JPL's Advanced Projects Design Team ("Team X"), cooperating with technology representatives from NASA's Ames and Langley Research Centers, conducted a series of studies of missions delivering multiple deep atmospheric entry probes to Jupiter. These studies generated multiple conceptual designs for the probes, with varying levels of technology investment, and conceptual designs for the carrier-relay spacecraft (CRSC) that delivers and supports the probes. New studies conducted in October and November of 2001 expanded on the older studies, designing probes that use only currently available (as of October 2001) technologies, or currently funded technology developments. They also adopted new approaches for improving the probes' link window durations and data return. The Thermal Protection System (TPS, or "heat shield") is the one exception to the technology constraint, requiring money for reactivating the Ames arcjet wind tunnel facility for validation and testing, and for development of structural and fabrication techniques for a TPS material to replace the no-longer-available carbon phenolic used on the Galileo Probe. Finally, new studies incorporated and expanded upon the 2001 Team X studies and earlier studies (summer 2001) that suggest a Jupiter Deep Multiprobes (JDMP) mission could reduce development costs significantly by using a derivative of the INSIDE Jupiter Discovery mission's spacecraft as the CRSC.

WHY MULTIPLE DEEP PROBES?

WHY MULTIPLE?

- Ensure a representative sample of Jupiter's atmosphere
  - The Galileo Probe sampled a distinctly *non*-representative region
- Multiple probes address lateral compositional gradients
- Redundancy reduces overall program risk

WHY DEEP?

- Sample the full deep abundances of C, O, N, and S
- Sample bulk flows unaffected by sunlight

WHY PROBES?

- Most reliable technique for sampling the deep atmospheres of giant planets
  - Visible and IR remote sensing limited to pressure levels <~5 bars
  - Below 10-20 bar levels microwave radiometry has larger uncertainties
    - * Low vertical resolution
    - * Model-dependent interpretation
- Provide "ground truth" for extrapolating remote sensing observations

SCIENCE GOALS

1. Determine Jupiter's bulk composition and compositional gradients, especially as they relate to solar system formation and planetary evolution
2. Determine Jupiter's atmospheric chemistry
3. Determine Jupiter's atmospheric structure and dynamics
4. Determine the spatial variability in and below Jupiter's troposphere

MEASUREMENT OBJECTIVES

Each of the following are measured as a function of depth, at three different latitudes:

1. Mixing ratios of the primary bearers of key elements, especially C, O, N, and S, and diagnostic species (noble gases, disequilibrium species)
2. Atmospheric structure: temperature, pressure, and density
3. Bulk flow velocity (wind)
4. Cloud characteristics: composition, density, particle size
5. Vertical radiant energy flux
6. Ortho- to para-H_2 ratio
7. Isotopic ratios for selected elements

CANDIDATE INSTRUMENT COMPLEMENT

1. Gas chromatograph / mass spectrometer (GCMS), range 1-300 AMU
2. Atmospheric Structure Instrument package, with thermometers, pressure transducers, and accelerometers
3. Nephelometer
4. Net Flux Radiometer
5. Acoustic Velocity instrument, for ortho- to para-H_2 ratios

(6. Stable reference oscillator for Doppler Wind experiments?)

DATA RETURNED

The GCMS data, losslessly compressed to 15-20 kb per sample, represent the bulk of the data returned by each probe. At the lowest relay link data rates, which occur at the deepest levels of penetration (20-100 bar levels), this allows for one GCMS sample every 50-70 s, or roughly 30 samples over a depth interval of less than two atmospheric scale heights. Other instruments' measurements can be made more frequently with insignificant impact on data rate requirements. Higher in the atmosphere, decreased column densities of ammonia and water allow data rates up to ~1 kbps, ensuring more-than-adequate sampling from the tropopause to the 20 bar level. The last hour of descent would return ~2 Mb of data; additional link window duration provides more time in the 0.1 - 20 bar levels (by allowing more time under a parachute, for example), returning data at 0.6 - 1 kbps. These data rates assume ammonia and water deep abundances about four times solar.

PROBE DESIGN FEATURES

Entry probes designed in the 1996-7 studies featured low masses, 75 to 110 kg depending on the level of technology investment. But even the 110 kg version involved some technology investment, an assumption that may or may not be supported in the current programmatic climate. Those designs used data relay system designs similar to that on the Galileo Probe: a relatively modest RF power amplifier fed a medium-gain antenna (MGA), whose main beam half-width (HWHM) was ~22°. This kept the mass of the primary batteries to a reasonable fraction of the probe mass. An unfortunate consequence of this strategy was that Jupiter's high rotation rate limited link window durations to about an hour or less, a rather severe constraint given the large vertical range to be sampled.

The newer designs incorporate new technologies developed elsewhere since the earlier studies. For example, GCMS developments since 1997 will soon yield instruments with performance, mass, and power specs that closely mirror those used in the 1997 studies, without significant investment by a multiprobes project. Notably, newer, higher-specific-energy primary battery technologies permit significantly more RF power without large mass growth in the power subsystem. This allows a change in the relay link approach: instead of relying on an MGA to provide adequate data rates, the new design uses more RF power through a low-gain antenna (LGA) with a 60° main beam half-width, yielding link window durations up to two hours. Other advances in telecommunication systems design allow multiple data-rate changes during descent without significant time lost for re-lock, increasing the net returned data volume.

However, the net effect of avoiding technology investments was to increase the total entry mass of the probes. The new design masses ~160 kg, 75 kg of which is TPS. A three-probe mission using this design must carry 480 kg of probes, plus the mounting and deployment hardware, compared to the 225-330 kg of the advanced-technology probes from the 1997 studies. This still compares favorably with the Galileo Probe, which massed 339 kg, about half of which was TPS.

THE *INSIDE JUPITER* SPACECRAFT AS THE CRSC

The INSIDE Jupiter spacecraft, originally designed to be a solar-powered, spin-stabilized platform for performing simple, close-in orbital studies of Jupiter, could be easily modified to serve as a low-cost JDMP CRSC. IJ's general performance requirements (*i.e.*, spin stabilization, pointing control, *etc.*) match well those for a JDMP CRSC. But other requirements are much less demanding for a CRSC than for the IJ orbital mission. Orbital operations in Jupiter's harsh environment inherently involve a relatively heavy spacecraft: a large propulsion system is needed for orbit insertion, much shielding and redundancy is needed for radiation tolerance, *etc.* Various aspects of IJ's science mission impose additional requirements, such as magnetic cleanliness of spacecraft systems. All these impact total mission cost.

Simpler CRSC requirements allow mass- and cost-saving modifications to an IJ-CRSC spacecraft. Obvious deletions include the large propulsion system and its thermal control subsystem, the orbital-mission science instruments and their support electronics and shielding, the parts of the telecommunications subsystem dedicated to radio science experiments, and some spacecraft avionics shielding. These deletions have secondary benefits, such as decreasing power requirements that allow for smaller, lighter solar arrays, and decreasing structural mass. Other modifications have smaller contributions to mass reduction. The net effect of all these modifications on spacecraft mass is a reduction by nearly 1,000 kg. Eliminating the orbital-mission science requirements has additional cost benefits, such as eliminating the more expensive hardware and testing programs associated with magnetic cleanliness.

Some additions are necessary. A UHF relay receiver and planar-array HGA (beam half-width ~20°) enable the probe relay function. IJ's star scanners are not designed to operate in the high equatorial radiation fluxes near 4 Rj, so low-mass inertial systems currently being developed augment the attitude control system for the equatorial pass. Pointing drift under inertial reference is not a problem due to the loose UHF HGA pointing requirements during the relay phase. Of course, there must be a deployment system for the probes. The space vacated by the primary propulsion system, aligned with the spacecraft's spin axis, provides an ideal location for the probes and their deployment system.

The total system mass depends on the mass of the probes and deployment system, which depends on the assumed technology investments. With no technology investment other than the minimal TPS development effort, the total flight system mass is ~260 kg less than the orbital-mission IJ spacecraft. Using the "maximal technology effort" probes from the 1997 designs would save an additional 250-300 kg. That effort would require a substantial investment in technology, mostly in advanced TPS development that reduces the TPS mass fraction from 45-50% to 25-35%. The "no new technology" design has over 500 kg of launch mass margin on a VEEGA trajectory to Jupiter using the smallest Delta IV launch vehicle, and could possibly fit on a Delta II Heavy. The "max-tech" design would certainly fit on a Delta II, and might use a faster trajectory such as a VEGA.

If INSIDE Jupiter is selected for implementation, modifying the existing IJ spacecraft design stands to save a significant fraction of the CRSC development cost, compared to the custom-CRSC mission. Any such mission is outside the current Discovery Program cost cap, due to the cost of the probes, but the option to use a Discovery-developed bus is still open. If the IJ-CRSC JDMP mission can fly on a Delta II Heavy instead of a Delta IV 4040, it saves a few million more on the launch vehicle cost. Using a VEGA trajectory instead of a VEEGA would save about a year of operations costs.

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